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GEODETIC JUNCTION OF FRANCE AND NORTH AFRICA BY SYNCHRONIZED PHOTOGRAPHS TAKEN FROM THE ECHO I SATELLITE

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GEODETIC JUNCTION OF FRANCE AND NORTH AFRICA BY SYNCHRONIZED PHOTOGRAPHS TAKEN FROM THE ECHO I SATELLITE

by ECHO I - May, 1964

In the course of this report, we intend:

-- to review the general principles of triangulation by satellite

-- to describe the material used

-- to indicate the general characteristics of the ground works for the France-North Africa junction:

Preparation of observations

Ground work

Practical results

-- to give a brief sketch of the work of processing the plates and of the computations programs.

-- to indicate the results obtained and the improvements envisaged.

Attached documents:

a) National Geographic Institute

Space Studies Group - Ballistic cameras

(installment published at the COSPAR Congress - May, 1964)

b) National Geographic Institute - Director of Geodesy

H. M. DUFOUR - Space Geodesy - Calculation tapes

(internal distribution of the I. G. N.)

I. GENERAL PRINCIPLES OF TRIANGULATION BY SATELLITE

The basic principle is quite simple: a luminous object is not seen against the same background of stars, according to the point on the Earth where the observer is stationed. It is understood that photography of this luminous object, along with photography of the stars which surround it, gives information which permits fixing the position of points on the Earth's surface, other points being presumed known.

To refine this idea: the solid earth, considered non-deformable, to which we attach a trihedral TXYZ, has in direction a motion known as a function of time on the stellar sphere, a motion given by position Astronomy; knowing the time means immobilizing the trihedral in the stellar field; each star thus constitutes an absolute direction, in the trihedral TXYZ; a direction given by the ephemerides of the stars.

In a similar fashion, we must "immobilize" the luminous object, which, practically speaking, necessitates making synchronous (or quasi-synchronous) observations from the different points on the globe which we want to tie together.

The luminous object can emit flashes of light: simultaneity is thus automatically assured. It may be continuously luminous: then it is necessary to create "artificial flashes" using, at diverse observation stations, revolving shutters whose rotation are synchronous.

"Anna" is such a flashing satellite: it has been useful for geodetic experiments. It is more costly than a continously luminous satellite, as it works only on command - and it is presently out of order.

ECHO I and ECHO II are continuously luminous satellites (it is ECHO I which was chosen for the France - North Africa junction.)

Practically speaking, photography involves:

-- a certain number of star photos which permit calculating the orientation of the camera.

-- a certain number of light flashes: in the case of the French observations, the shutter turns at the rate of sixty revolutions/minute, producing sixty luminous points in one minute, which we call "flashes".

Essentially the problem is to interpolate the position of the flashes among the known star positions; let us mention right away that the sixty flashes are brought together as one central flash, and that the direction for this central flash is obtained in the trihedral TXYZ.

Thus each photo givens a known direction SF, S being the station and F the fixed point. We shall see, apropos the France - North Africa junction, how the geodetic problem is discussed, starting from this fundamental principle.

Several results necessary to precision:

If angular precision of 1" (that is, 1/200,000th of a radian) is desired for SF, we must have:

- a 10^{-3} sec precision tolerance for the revolving shutter;
- accuracy of sideral time to 1/20th of a second;
- accuracy within two to three μ in the determination of star positions and flashes on the photographic plate (for a focal length of 30 cm.)

II. INSTRUMENTS

We refer the reader to document (a).

The apparatus includes, essentially:

-- a camera, focal length 30cm, furnished with a revolving shutter and with a leaf shutter.

-- a quartz chronometer, for regulating the revolutions of the shutter at the rate of one rev/sec, for photography of the satellite; and for releasing the leaf shutter for the star photos.

The entire apparatus is extremely simple and highly portable.

Notation of the hours is effected:

-- for the satellite, by direct reading on the revolving shutter calibration scale: each second blip of the time signal illuminates the frame of the shutter, always at the same point, thus permitting the observer to take a correct reading (at close to 10^{-3} sec).

-- for the stars: according to the same principle - on a revolving calibrated disk incorporated into the quartz chronometer.

III. THE GEODETIC LIAISON FRANCE - NORTH AFRICA (May, 1964)

Under the auspices of the National Center for Space Studies (C.N.E.S.), the National Geographic Institute was charged with effecting the France - North Africa liaison by means of synchronous photographic observations of the ECHO I satellite.

Known points:

- Lacanau (near Bordeaux, on the Atlantic)
- Agde (near Sète, on the Mediterranean)
- Oletta (Corsica)

Points to be determined:

- Hammaguir (West Sahara)
- Ouargla (East Sahara)

Actually, the five points are already known in the European Compensation system (called Compensation Europe 1950), and the work consists in comparing classical geodetic transmission with transmission by means of spatial geodesy.

Satellites used

The only observations retained were those made of ECHO I, which, by reason of its culmination at around 47.5°, is well suited to observation from the Mediterranean area.

The observations slope gradually from the 4th to the 26th of May. It was sometimes possible to obtain four useful passes in one evening.

ECHO II was similarly observed beginning May 20th, but no observations have been retained. ECHO II could have at most but one useful passage.

Geodetic configuration

In the final calculations, all the observations of absolute directions will be replaced by observational relations, which will permit definition of the unknown points (with their table of errors); but for the observations themselves, it is necessary to define a general line of work which will assure a priori a satisfactory overall configuration.

One may reason as follows:

1st point of view

The central meridian of the zone of observation has a longitude of around 2° East; the central parallel is at 38° latitude. The most important points for the liaison are the points of the satellite's trajectory, on the mean parallel, respectively to the West and to the East of the central meridian (points East of the vertical in the south of Italy, points West of the vertical in Spain). These points are determined by intersection from the three French bases. Their intersection determines the African points: considering the schematic, it becomes apparent that this latter intersection is a good one, the first one not being as desirable, since the French points constitute a rather narrow base.

2nd point of view

The set of astrally defined directions determine a certain number of planes: these planes, combined, permit definition of the right lines joining the points on the ground.

Examining the schematic, one realizes that all the right lines of the schematic are thus well defined, save the right line Ouargla-Hammaguir, as it was difficult to have African points not situated in the cone of the shadow.

Here again, one realizes that the African points are defined by intersection starting from a French base which is rather narrow.

Forecast of the passages

For each passage of the satellite, the point of the satellite's trajectory to be aimed at is in actual fact imposed; the works coordinator chooses this point as a function of diverse elements:

-- first of all, the necessity of a generally well formed geometric figure, as we have noted

-- observation hours suitable for star photography: from this point of view, the stations at high latitudes, in summer, are very unsuitable.

-- it is also necessary that the satellite leave the shadow cone soon enough so that the observers are not surprised (actually, the hour of the satellite's arrival often can not be predicted to better than about five minutes).

Theoretically, it should be possible to take into account previous successful evenings of observation; practically, this is scarcely possible; in fact, the general coordinator establishes a plan and follows it more or less rigidly.

For the passage forecasts, the ECHO I ephemerides are used, as furnished by the Smithsonian Astrophysical Observatory of Massachusetts.

Upon reception of an ephemeride, the passages are numbered, the ephemeride for around 15 days is extrapolated, the points of passage are chosen - that is to say, the points in the sky at which the balistic cameras will have to be aimed; an electronic program then furnishes a statement indicating for each station all the elements of observations.

In practice, between the elements of the extrapolated ephemeride and the values of the following ephemeride, we currently encounter differences on the order of 10 minutes in time and 2 to 3 degrees in longitude. These differences, although disagreeable, are acceptable in observation. They bear out the fact that ECHO I, being very light, is extremely sensitive to radiation pressure.

Ground operations

The task of taking the pictures necessitates only two operators, but in practice it is a good idea to provide a team of three: actually, during the useable time period, photographs are taken every two hours in the course of the night, every night; it is desirable under these conditions to provide for each operator one night's rest every three nights.

The picture-taking operation includes the following phases:

(placement of the camera in the station, 2 hours before the observation)

(starting of the chronometer)

Placement of a plate in the camera

Setting of the chronometer, by time signals

Photography of the stars (first shot)

Starting of the shutter disk; regulation by time signals

Photography of the satellite, at the rate of one shot per second, save the sixty-second blip of each minute, which is eliminated by a disk worked by an operator*

Stopping the disk: photography of the stars (second shot)

Photography of the synchronizing marks at the base of the camera

Replacement of the plate

Setting up of the camera for the next observation.

Operations include as well:

-- Development of the plate

-- Printing of a paper with the following information: direction of the

*The operator hears the time signals and places the disk in front of the objective when he hears the long signal of the full minute.

satellite's passage, numbering of the minutes....direction of diurnal movement.

The important elements of ground operations are essentially:

-- The stability of the apparatus during the interval of time which separates the two shots of the stars; this interval is presently fifteen minutes, and will be reduced to less than ten minutes.

-- Noting of the hour on the turning shutter, which must be effected within 10^{-3} seconds.

Success of the observations

About sixty positions of the satellite were selected to be photographed. (each one including sixty shots). Here is the tabulation of successful photos:

Hammaguir:	15	Ouargla:	40
Oletta :	40	Agde :	35
Lacanau :	25		

Naturally, every point aimed at simultaneously by at least two stations is useable. Theoretically, the probability of one position in five successful negatives is:

$$\frac{15}{60} \times \frac{40}{60} \times \frac{40}{60} \times \frac{35}{60} \times \frac{25}{60} \neq \frac{1}{37}$$

(In fact, there were only two points entirely successful out of 60).

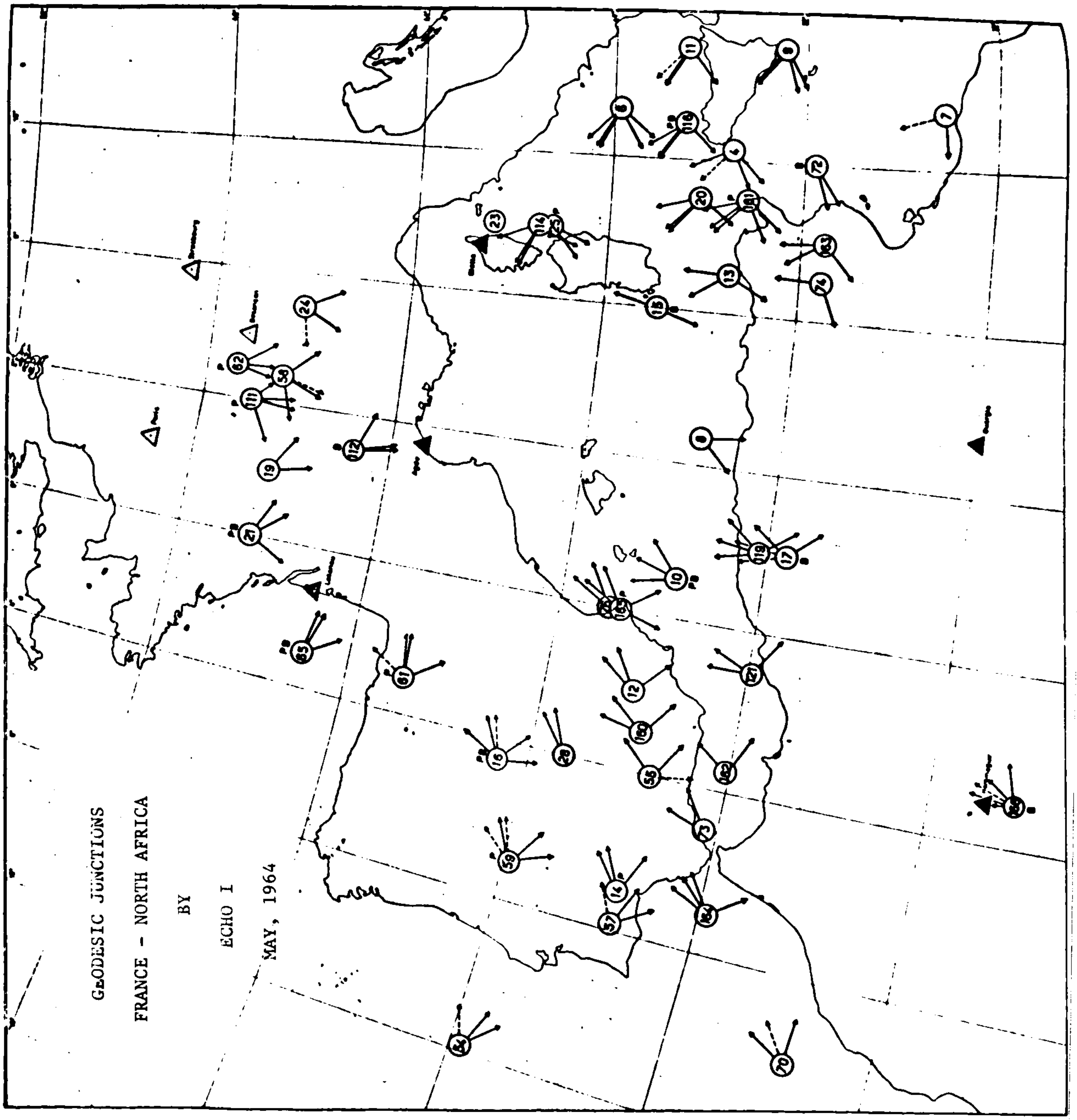
IV PROCESSING OF THE PLATES - CALCULATIONS

We cannot here go into the complete details of this last phase of the work.* We can only indicate the fundamental subdivisions; we proceed to the following operations:

A) Calculations of the theoretical coordinates of the stars on the plates

B) Observation of the plates with a comparator

* See document (b) for additional explanations.


GEODESIC JUNCTIONS
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BY
ECHO I
MAY, 1964

C) Calculations of the formulas giving the directing cosines of the flashes in the terrestrial cartesian system

D) Intersection of the flashes starting from the approximate coordinates of the stations

E) Calculations of the unknown coordinates of the stations starting from the known coordinates.

The characteristics of these diverse operations are given in the following pages. All the calculations were made on the CAB 500 of the Geographic Institute.

Other calculations

In addition, there took place the careful establishement of the coordinates of the liaison points in the terrestrial cartesian system by means of classical geodesy:

Planimetrically, the geographic coordinates (λ ϕ) for North Africa in the European Compensation system are available: their accuracy is close to 10m.

Altimetrically, the altitudes H of the different points above the International Ellipsoid are calculated by integration of the deviations from the vertical to the astronomic points.

1st calculation: French network

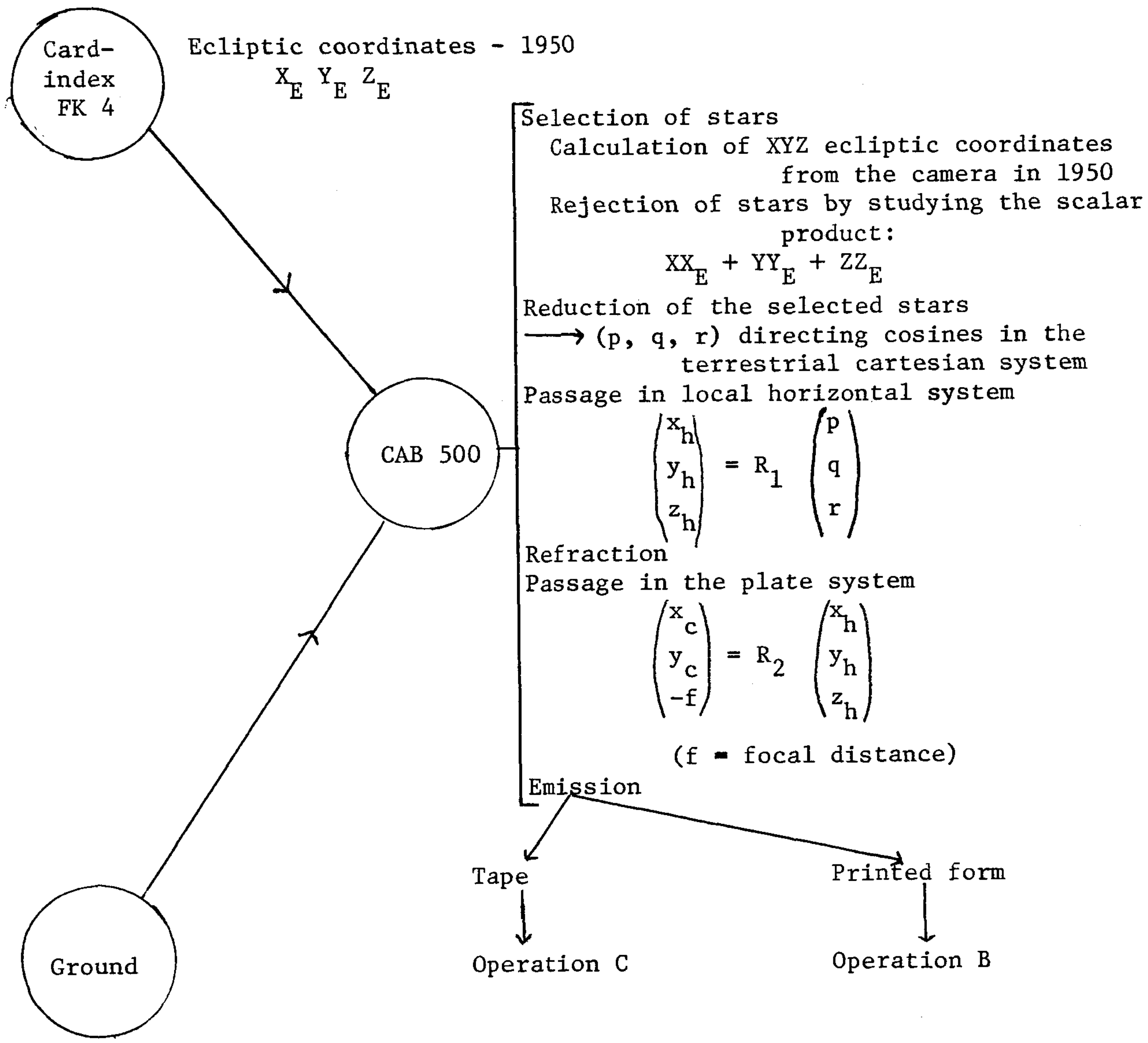
2nd calculation: South of France - Italy - Spain - North Africa

The French network is dense enough to make the results worthy of confidence. The second network is made up of points rather spread apart from each other. After cross-checking, it may be estimated that precision to a decameter is preserved here as well.

The calculation is effectuated by means of astronomical levelling, placing relations of observations between each point and the nearest points: it is admitted that each difference of level has an error independent from the others and proportional to the distance; these hypotheses are not absolutely rigorous: it is proposed to work up the calculations statistically most valuable, which are presently in preparation.

The approximate coordinates of the stations (calculations D and E) are furnished by the terrestrial cartesian coordinates, issued from the coordinates (λ ϕ H), calculated on the International Ellipsoid.

A) <u>Calculation of theoretical coordinates from the stars on the plates</u>



DZ: zenith distance
AZ: azimuth
TU: universal time for the stars
TU: universal time for the flashes
P : pressure
T : temperature (Refraction)

B) Observations at the comparator

Observation of a plate necessitates in practice a day's work for two operators. It is most exacting.

The operators utilize the approximate coordinates $(x_c y_c)$, given by calculation A, in order to position the plate under the comparator.

They then note the elements of the plate in the following order:

- Synchronizing marks at the bottom of the camera - Stars - Flashes	operator 1, operator 2 acting as secretary
- Flashes - Stars - Synchronizing marks at the bottom of the camera	operator 2, operator 1 acting as secretary

The use of two operators has the following advantages:

-- Systematic observational errors show up in the course of the work itself; sometimes these may be remedied on the spot

-- The secretary figures the averages in the course of the work: any error is immediately corrected

-- The operators keep each other company (a rather fastidious task!) and they can rest their eyes 50% of the time

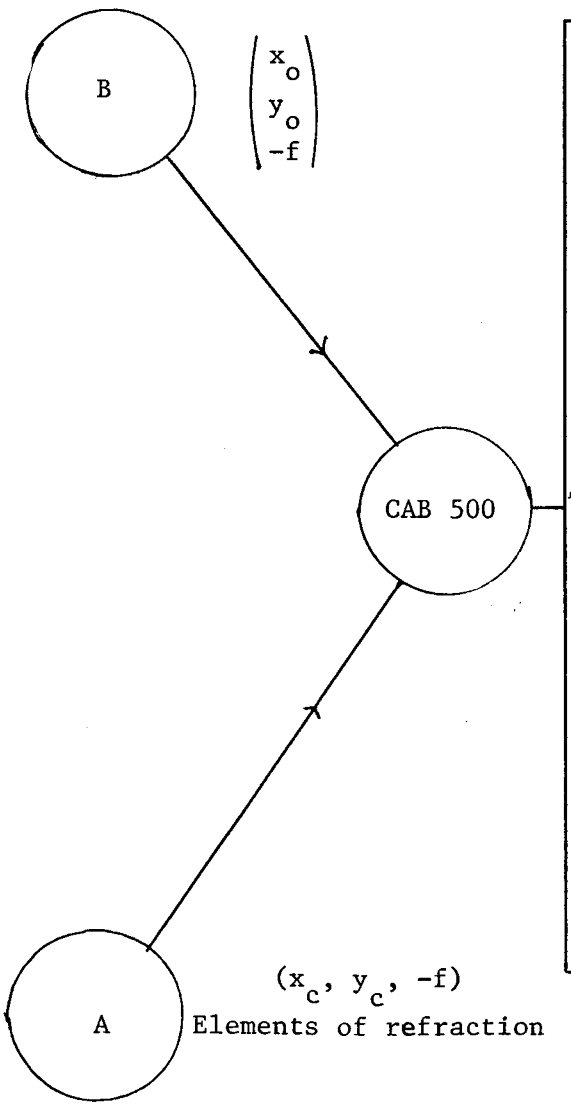
Following the work of comparator observations, a smoothing out of the flashes is effected; instead of 60 flashes in the minute chosen, only 11 flashes are kept, corresponding to seconds 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, and 55. The smoothing consists in replacing the observation z_i of the second i by the mean obtained by making the

the hypothesis that the curve z(t) is representable by a function of the second or third degree in the interval (i-4, i+4). This mean, obtained by use of least squares, is the following:

$$Z_i = \frac{59z_i + 54(z_{i+1} + z_{i+1}) + 39(z_{i-2} + z_{i+2}) + 14(z_{i-3} + z_{i+3}) - 21(z_{i-4} + z_{i+4})}{231}$$

The smoothing out, effected on an office calculating machine, permits correction of mistakes: only the smoothed out coordinates (x_o, y_o) are punched onto the tape. We then go on to stage C.

C) <u>Processing of the plates</u>



<u>Use of the stars</u>: $x_o y_o\ -f$

Correction of radial distortion
Examination of the homographic formula, in least squares

$$\begin{pmatrix} x_o \\ y_o \\ -f \end{pmatrix} \longrightarrow \begin{pmatrix} x_c \\ y_c \\ -f \end{pmatrix}$$

<u>Application to the flashes</u>

Correction of distortion
Application of the homographic formula
$\longrightarrow (x_c y_c\ -f)$
Return to terrestrial cartesian system:

$$\begin{pmatrix} p \\ q \\ r \end{pmatrix} = R_1{*}\ R_2{*} \begin{pmatrix} x_c \\ y_c \\ -f \end{pmatrix}$$

<u>Complementary corrections</u>

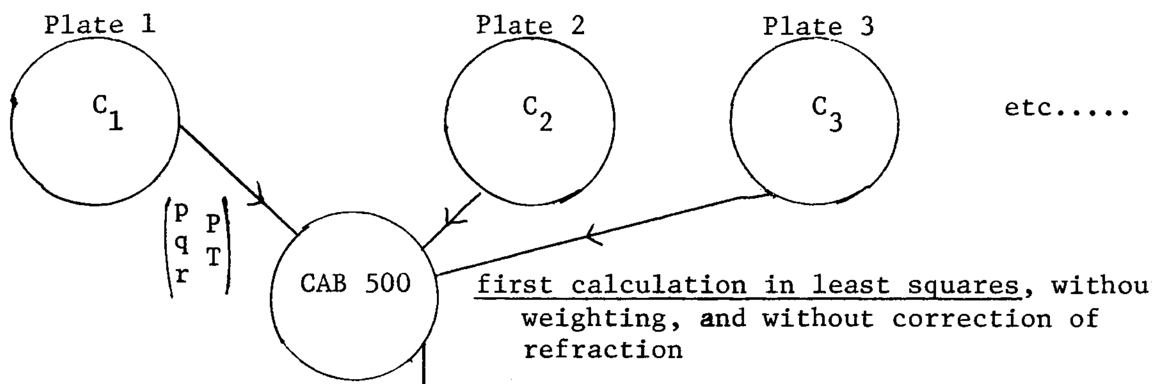
Time of propagation of the radio signals
Correction to amount to the even second
Correction of position on the plate

<u>Printing of a tape</u>

$\begin{pmatrix} p \\ q \\ r \end{pmatrix}$ of the flashes and elements P, T for refraction

D) <u>Intersection</u>

Several simultaneous plates give a <u>series</u>



<u>first calculation in least squares</u>, without weighting, and without correction of refraction

→Approximate coordinates of the flashes

<u>second calculation</u>, with weighting, and with correction of refraction

→Coordinates $X_F Y_F Z_F$, the most coherent as a function of the coordinates of the stations

Printing of a tape

Operation E

E) <u>Geodetic calculation, properly so-called</u>

Regrouping of the series: each plate yields an observational relation in a general system of least squares.

For this relation, a smoothed-out value of the central flash is used.

For each plate

- Approximate coordinates of the central flash
- Orientation (p q r) of the central flash
- P and T for calculation of refraction
- Orientation of the sun

<u>For each flash</u>

- Refraction correction
- Phase correction
- Placing of the observational relation
- Normalization
- Elimination of the flash coordinates

CAB 500

Summation of the equations:

1) resulting from *a priori* liaisons between the station points (known points, known distances.....)
2) resulting from the normal equations, after elimination of the flashes

→ Table N of weights of the coordinates

Table N^{-1} of variance
Calculation of mean quadratic error of a direction

Coordinates of the stations

Approximate coordinates of the stations

Liaisons between the stations

V - RESULTS OBTAINED - PLANNED IMPROVEMENTS

In a general fashion, the Geographic Institute has been occupied with the production of highly transportable equipment, and with the achievement of effective experiments; progressively, we hope in the future to perfect the various operations, according to successive problems which require increased precision.

Presently, we expect from the France - North Africa experience theoretical angular precision of 1/100,000th of a degree (that is, two sexagesimal seconds), which corresponds, in gross fashion, to a precision of 20 m between the extreme geodetic points. It is not possible here to say anything definitive about the practical results, the first of which are just beginning to appear (operation D). (Furthermore, they do not match the theoretical precision noted above; this will oblige us to go over most carefully all the phases of the calculations.)

We hope in the future to improve the precision of the measurements thanks to the following improvements:

-- Regulation of the entire picture-taking operation by quartz chronometer; presently, this clock assures regular rotation of the shutter disk, but not its setting at the hour, which is made directly on time signals. In the future, the chronometer will also perform this hourly setting, itself being regulated, always by the intermediary revolving disk, by different time signals, before and after photography of the satellite and of the stars. This latter operation may thus be cut down to less than ten minutes.

-- To use thick photographic plates (6mm), rigorously flattened

-- To use fast emulsions, in order to increase the number of stars shot in one session.

-- To take two shots before and two shots afterwards of the stars

-- To place systematically in each station two cameras in parallel: this procedure improves the precision of the directions to the ratio $\sqrt{2}$ and permits the easy disclosure of any discrepancy

-- To air-condition, at least partially, the picture-taking apparatus and the quartz clock.

Translated for the National Aeronautics and Space Administration by the FRANK C. FARNHAM COMPANY.